CONFERENCE ON DISARMAMENT

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PROGRESS REPORT TO THE CONFERENCE ON DISARMAMENT ON THE FORTY-SECOND SESSION OF THE AD HOC GROUP OF SCIENTIFIC EXPERTS TO CONSIDER INTERNATIONAL CO-OPERATIVE MEASURES TO DETECT AND IDENTIFY SEISMIC EVENTS

1. The Ad Hoc Group of Scientific Experts to Consider International Co-operative Measures to Detect and Identify Seismic Events, initially established in pursuance of the decision taken by the Conference of the Committee on Disarmament on 22 July 1976, held its forty-second formal session from 27 November to 1 December 1995, in the Palais des Nations, Geneva, under the Chairmanship of Dr. Ola Dahlman, Sweden. This was the thirty-fourth session of the Group, convened under its new mandate by the decision of the Committee on Disarmament at its 48th meeting on 7 August 1979.

2. The Ad Hoc Group is open to all Member States of the Conference on Disarmament. It is also open on a standing basis to all non-Member States which have been invited upon their request by the Conference on Disarmament to participate in its work. Accordingly, scientific experts and representatives of the following Member States of the Conference on Disarmament participated in the session: Australia, Belgium, Bulgaria, Canada, China, France, Germany, Hungary, India, Italy, Japan, Mongolia, Netherlands, Pakistan, Poland, the Russian Federation, Sweden, the United Kingdom of Great Britain and Northern Ireland, and the United States of America.

3. Scientific experts and representatives from the following non-Member States of the Conference on Disarmament participated in the session: Austria, the Czech Republic, the Democratic People's Republic of Korea, Denmark, Finland, Israel, Kazakhstan, New Zealand, Norway, the Republic of Korea, South Africa, Spain, Switzerland, Turkey and Ukraine.

4. During the session 24 papers concerning national investigations related to the work of the Ad Hoc Group were presented by participating experts and reviewed by the Group.

5. The main topic of the session was the consideration of an auxiliary network of seismic stations for the envisaged International Monitoring System (IMS). The Group reviewed the substantial technical and scientific material on this issue that had been prepared in advance of the session by the three GSETT-3 Working Groups on Planning, Operations and Evaluation.

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6. For the auxiliary network, the Ad Hoc Group agreed on 111 stations listed in Table 1 to primarily cover the continents, and on 17 additional stations listed in Table 2 on small islands to provide for improved coverage of ocean areas. The Ad Hoc Group understands that possible synergy with the hydroacoustic component of the IMS will be considered in the IMS Expert Groups. These deliberations are expected to clarify which of the stations in Table 2 may actually be required and included in the IMS auxiliary seismic network. The six stations in Table 2 that are marked by a cross in the column on the far right, are of special interest to seismic monitoring.

These auxiliary seismic stations would then supplement the primary seismic network of 50 stations listed in the bracketed text of CD/1364, pp. 92-94.

All stations proposed for the auxiliary network are also shown on a map, together with the primary network in Figure 1. The auxiliary stations are shown as triangles whereas the primary stations are shown as squares. The 17 stations in Table 2 are shown as inverted triangles in this figure.

7. The Ad Hoc Group noted that the two principal purposes of the auxiliary network are:

- to improve the location accuracy of seismic events detected by the primary network

- to more finely characterize the seismic sources for purposes of event identification

In its consideration of the auxiliary network, the Group took into account available and planned seismic stations of suitable quality world-wide, and applied the following general selection criteria:

- auxiliary stations should primarily cover the most seismically active regions of the world, with emphasis on regions where earthquakes look explosion-like

- auxiliary stations should also be located in regions where there is extensive mining activity that produces large seismic signals

- auxiliary stations should furthermore be located in areas where the azimuthal coverage of the primary network is poor.

Another factor taken into account by the Group was the desirability that some of the auxiliary stations should be capable of acting as substitute primary stations in the event that one or more of the primary stations suffers a long term outage for some reason.

Details on the criteria and procedures leading to the selection of the recommended auxiliary network are given in Annex 1.

It is recognized that the availability of some of these stations will depend on consideration of the costs of upgrading existing installations and the willingness of the host countries to provide these facilities.

8. The recommended auxiliary network is based upon computer simulations of the performance of various network configurations, making extensive use of the data and results achieved during GSETT-3. The resulting combined primary-auxiliary network should, in the view of the Ad Hoc Group, be capable of locating seismic events in continental areas of magnitude 4 or higher with an uncertainty of no more than 1000 square kilometres. Furthermore, the network would have sufficient coverage to allow source characterization criteria to be applied to such events with an adequate azimuthal distribution.

To locate events with an uncertainty of no more than 1000 square kilometres requires careful calibration of the recommended network against seismic events with known locations or locations estimated with high accuracy by local or regional networks. Such calibrations, which should be carried out with the newly-established system, are needed to eliminate the systematic bias created by heterogeneities within the earth. This requires a systematic analysis of suitable events as they occur and results in a gradual improvement of the accuracy of the system. The need for calibration is one reason why the Ad Hoc Group supports the continued development and testing of the IMS to provide for a seamless transition into the eventual International Monitoring System. This would entail continuing the flow of data from IMS stations to the prototype International Data Center.

Since the Ad Hoc Group's considerations of the number of stations in the auxiliary network have been based largely on theoretical grounds (simulation), it is suggested that the number and locations of stations in the auxiliary network be updated over time as operational experience is gained.

9. The Ad Hoc Group recognized that there are many additional stations not included in this recommended network which could make a positive contribution to the location and

identification of seismic events. The Group noted that a number of states are prepared to make available supplementary data from such national facilities.

10. The Ad Hoc Group also reviewed the progress of its GSETT-3 experiment. The Group noted that four new primary (Alpha) stations and six new auxiliary (Beta) stations have been added to GSETT-3 since August, so that the total number of stations in the network now comprises 41 primary and 81 auxiliary stations.

The GSETT-3 primary network is gradually approaching the primary network agreed for the IMS. Similarly, the auxiliary network will approach the auxiliary IMS network once a decision on the IMS auxiliary network has been made. The GSETT-3 has provided most useful information and experience on the use of auxiliary stations which has been utilized in preparing the Group's recommendation for the IMS auxiliary network.

Work is going on at the IDC to fine tune the detection algorithms of the individual stations to optimize the detection capability of the system. Work is also under way, and results were presented to the Group, on procedures to characterize observed seismic events.

11. The Ad Hoc Group reviewed a preliminary report on the evaluation of GSETT-3. The Evaluation Group was asked to present a draft of a final report for the next session in February 1996, and the Group plans to report on the results of the evaluation to the Conference on Disarmament following that session.

12. For planning purposes, the Ad Hoc Group envisages the need for two further sessions later in 1996, with suggested dates 20-31 May and 5-16 August. This will be further discussed during the February 1996 session.

13. The Ad Hoc Group noted with appreciation the convening of an informal Technical Workshop on CTBT monitoring and GSETT-3 in Lahti, Finland, 12-14 October, 1995. Thirty experts from 11 countries participated in that Workshop, which made an important contribution to the further progress of GSETT-3.

14. The Ad Hoc Group likewise appreciated the convening of an informal regional GSETT-3 Workshop in Argentina, 20-22 November 1995. This Workshop was convened with the objective of increasing awareness of the GSETT-3 experiment and encouraging participation from seismological institutes in the Central and Latin American regions. The Workshop was hosted by Argentina at its National Institute for Seismic Prevention (INPRES) in San Juan. The Workshop was well attended by seismologists and government representatives from many countries in Central and Latin America.

15. The Ad Hoc Group also discussed its future plans. The Group noted that its next session, as already approved by the Conference on Disarmament, will be convened from 12 through 23 February, 1996, in order to continue carrying out the work plan presented in the Progress Report from the 41st Session. A draft work programme for the next session is presented in Annex 2. The work programme will be tailored to meet as much as practicable the information needs of the Ad Hoc Committee on a Nuclear Test Ban and its Working Group on Verification.

Recommended IMS Auxiliary Seismic Stations

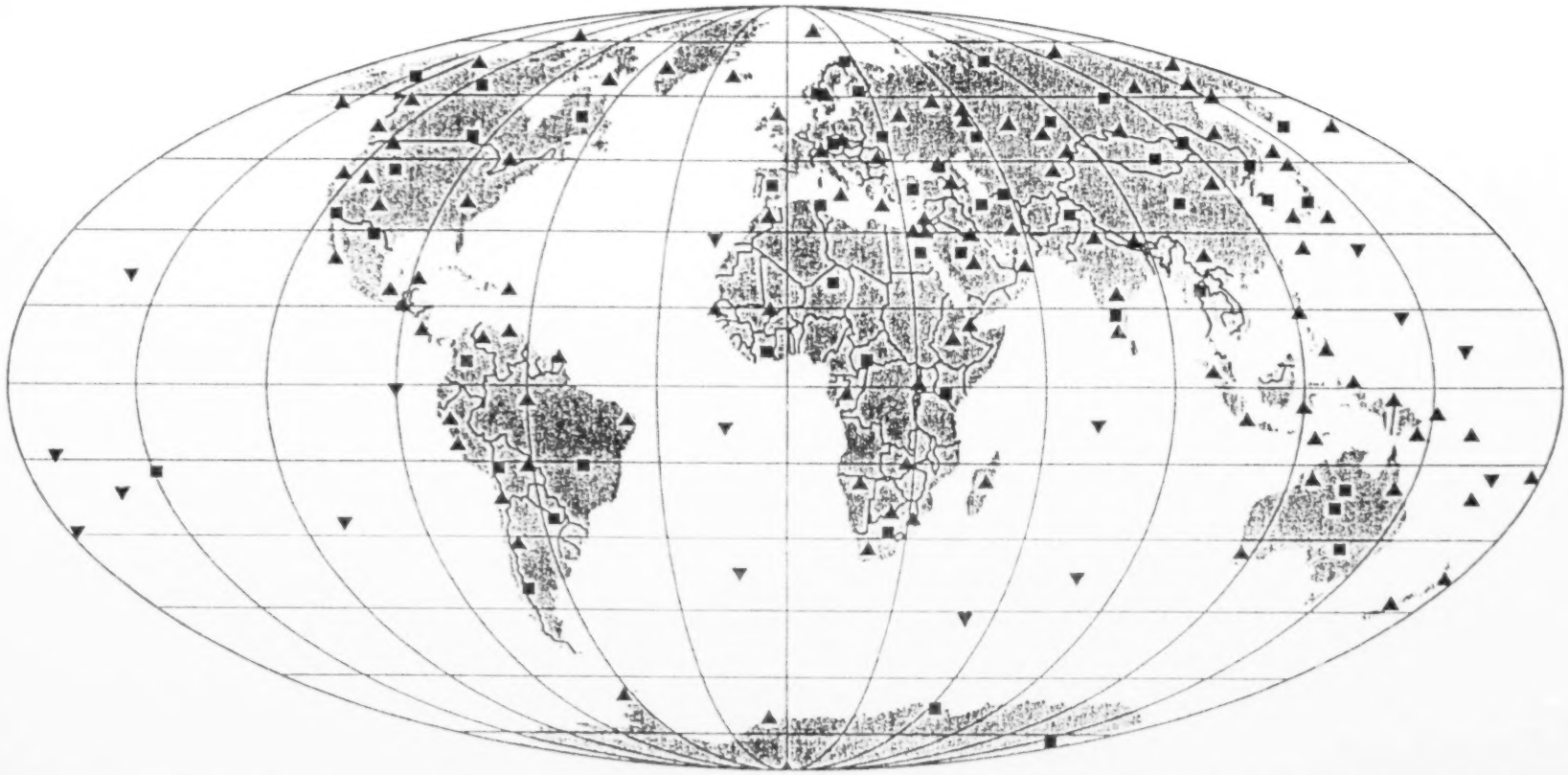

Figure 1: The figure shows the primary stations (squares) already agreed for the IMS and the auxiliary stations (triangles) recommended by the GSE. Note that the auxiliary network will contain four additional stations; two in China at locations to be recommended by China, one in India at a location to be recommended by India, and one in the South Atlantic at a location to be determined.

Explanation for Tables 1 and 2:

Tables 1 and 2 provide details on the stations recommended for the auxiliary network. The tables give the rationale for the inclusion of the various stations, in accordance with the station selection criteria and procedures outlined in paragraph 7. The meaning of the entries in the "Rationale" column of the tables is as follows:

S : Station is in a seismically active region

M : Station is in an area of extensive mining

C : Station is in an area where the azimuthal coverage of the primary station network is poor

B : Station could serve as a backup for one or several primary stations (and would then need to have continuous communications)

The "Status" column of the tables gives the operational status of the stations, with codes as follows:

ED : Existing digital station (note that communications link may not be in place)

PL : Planned digital station

PR : Proposed digital station

EA : Existing analog station

Table 1:

Recommended IMS Auxiliary Stations to Cover Continents

No.	Location	Station name and code	Station type	Lat	Long	Rationale	Status
North America							
1	Canada	Mould Bay MBC	3-C	76.242	-119.360	C	ED
2	Canada	Iqaluit FRB	3-C	63.747	-68.547	C	ED
3	Canada	Bella Bella BBB	3-C	52.185	-128.113	S	ED
4	Canada	Sadowa SADO	3-C	44.769	-79.142	M,C	ED
5	Canada	Dease Lake DLBC	3-C	58.417	-130.060	S,B	ED
6	Canada	Inuvik INK	3-C	68.307	-113.520	S,C	ED
7	Denmark	Søndre Strømfjord, Greenland SFJ	3-C	67.050	-50.300	C	PL
8	USA	Kodiac Island KDC	3-C	57.750	-152.490	S	PR
9	USA	Attu ATTU	3-C	52.800	172.700	S	ED
10	USA	Newport NEW	3-C	48.263	-117.120	S, M	ED
11	USA	Yreka YBH	3-C	41.730	-122.710	S	ED
12	USA	Elko ELK	3-C	40.745	-115.239	S,B	ED
13	USA	Albuquerque ALQ	3-C	34.946	-106.457	S,M	ED
14	USA	Tuckaleechee Caverns TKL	3-C	35.658	-83.774	M,C	ED
15	Mexico	La Paz, Baja California LPBM	3-C	24.170	-110.210	S	PL

No.	Location	Station name and code	Station type	Lat	Long	Rationale	Status
16	Mexico	Tepich TEYM	3-C	20.210	-88.340	C	PL
17	Mexico	Tuzandepeti TUVM	3-C	18.030	-94.420	S	PL
18	Costa Rica	Las Juntas de Abangares JTS	3-C	10.290	-84.950	S	ED
19	Guatemala	Rabir RDG	3-C	15.010	-90.470	S	EA
20	USA	San Juan SJG	3-C	18.110	-66.150	S	ED
South America							
21	Venezuela	Santo Domingo SDV	3-C	8.880	-70.630	S	ED
22	Venezuela	Puerto la Cruz PCRV	3-C	10.180	-64.640	S	EA
23	France	Kourou KOG	3-C	5.207	-52.732	C	ED
24	Brazil	Pitinga PTGA	3-C	-3.060	-60.000	C	ED
25	Brazil	Rio Grande do Norte RGNB	3-C	-6.910	-36.950	C	PL
26	Peru	Cajamarca ?	3-C	-7.000	-78.000	S,M,B	New
27	Peru	Nana NNA	3-C	-11.990	-76.840	S,M	ED
28	Chile	Limon Verde LVC	3-C	-22.590	-68.930	S,M	PL
29	Argentina	Coronel Fontana CFA	3-C	-31.607	-68.239	S,B	ED
30	Bolivia	San Ignacio SIV	3-C	-15.991	-61.072	S	EA
Europe							
31	Iceland	Borgarnes BORG	3-C	64.750	-21.330	S	ED
32	Norway	Spitsbergen SPITS	Array	78.178	16.370	S	ED
33	Sweden	Hagfors HFS	Array	60.134	13.697	B	ED

No.	Location	Station name and code	Station type	Lat	Long	Rationale	Status
34	United Kingdom	Eskdalemuir EKA	Array	55.333	-3.159	C	ED
35	Switzerland	Davos DAVOS	3-C	46.839	9.794	S,B	ED
36	Czech Republic	Vranov VRAC	3-C	49.308	16.594	M	ED
37	Russia	Kislovodsk KIV0	Array	43.956	42.695	S,B	ED
38	Russia	Obninsk OBN	3-C	55.114	36.569	M,C	ED
39	Russia	Kirov KIRR	3-C	58.430	50.020	M	ED
40	Russia	Arti ARU	3-C	56.430	58.563	M,C	ED
41	Romania	Muntele Rosu MLR	3-C	45.492	25.944	S	ED
42	Italy	Enna, Sicily ?	3-C	37.500	14.300	S	ED
43	Greece	Anogia, Crete IDI	3-C	35.280	24.890	S	ED
Africa							
44	Morocco	Mfdelt MDT	3-C	32.820	-4.610	S,B	ED
45	Egypt	Kottamya KEG	3-C	29.930	31.830	S	ED
46	Ethiopia	Furi FURI	3-C	8.900	38.680	S,B	PL
47	Djibouti	Arta tunnel ATD	3-C	11.530	42.847	S	ED
48	Uganda	M'barara ?	3-C	0.360	30.400	S	PL
49	Zambia	Lusaka LSZ	3-C	-15.280	28.190	S,M	ED
50	Namibia	Tsumeb TSUM	3-C	-19.200	17.580	C	ED
51	Botswana	Lobatse LBTB	3-C	-25.015	25.597	M,B	ED

No.	Location	Station name and code	Station type	Lat	Long	Rationale	Status
52	Swaziland	Mbabane SWL	3-C	-26.312	31.154	C,M	ED
53	South Africa	Sutherland SUR	3-C	-32.380	20.810	M	ED
54	Madagascar	Antananarivo TAN	3-C	-18.920	47.550	C	EA
55	Gabon	Bambay BAMB	3-C	-1.660	13.610	C	PL
56	Mali	Kowa KOWA	3-C	14.500	-4.020	C	PL
57	Senegal	M'Bour MBO	3-C	14.391	-16.955	C	ED
Asia							
58	Armenia	Garni GNI	3-C	40.050	44.720	S	ED
59	Israel	Eilath MBH	3-C	29.790	34.905	S	ED
60	Israel	Parod PARD	Array	32.550	35.260	S	ED
61	Oman	Wadi Sarin WSAR	3-C	23.000	58.000	S	PL
62	Iran	Kerman KRM	3-C	30.280	57.070	S,B	PL
63	Kuwait	Kuwait City ?	3-C	29.200	46.200	S	New
64	Saudi Arabia	Ar Rayn RAYN	3-C	23.600	45.600	C	PL
65	Kyrghyzstan	Ala-Archa AAK	3-C	42.640	74.490	S	ED
66	Kazakhstan	Kurchatov KURK	Array	50.715	78.621	M,B	ED
67	Kazakhstan	Borovoye BRVK	Array	53.058	70.283	M,C	ED
68	Kazakhstan	Makanchi MAK	3-C	46.808	81.977	S	ED
69	India	New Delhi NDI	3-C	28.690	77.220	S	PR

No.	Location	Station name and code	Station type	Lat	Long	Rationale	Status
70	India	Hyderabad HYB	3-C	17.420	78.550	M	ED
71	India	Kodaikanal KOD	3-C	10.230	77.470	C	PR
72	India	Site to be recommended by India					
73	China	Baijiatuan BJT	3-C	40.020	116.170	M,C	ED
74	China	Kunming KMI	3-C	25.150	102.750	S,M	ED
75	China	Site to be recommended by China					
76	China	Site to be recommended by China					
77	Nepal	Everest EVN	3-C	27.960	86.820	S	ED
78	Russia	Zilim UFA	3-C	53.850	57.050	M	ED
79	Russia	Magadan MA2	3-C	59.580	150.780	S	ED
80	Russia	Seymchan SEY	3-C	62.930	152.370	S,M	ED
81	Russia	Yuzhno-Sakhalinsk YSSK	3-C	46.986	142.689	S,B	ED
82	Russia	Tiksi TIXI	3-C	71.660	128.870	C	ED
83	Russia	Talaya TLY	3-C	51.580	103.640	S,M	ED
84	Russia	Urgal URG	3-C	51.100	132.360	S	ED
85	Russia	Bilibino BIL	3-C	68.039	166.372	C	ED
86	Russia	Yakutsk YAK	3-C	62.030	129.680	S	ED
87	Japan	Kamikawa-asahi, Hokkaido JKA	3-C	44.117	142.500	S	ED

No.	Location	Station name and code	Station type	Lat	Long	Rationale	Status
88	Japan	Kunigami, Okinawa JOW	3-C	26.833	128.283	S	ED
89	Japan	Hachijojima JHJ	3-C	33.117	139.817	S	ED
90	Japan	Ohita, Kyushu JNU	3-C	33.117	130.883	S	ED
91	Phillippines	Tagaytay TGY	3-C	14.100	120.940	S,M	ED
92	Phillippines	Davao DAV	3-C	7.090	125.570	S	ED
93	Indonesia	Sulawesi ?	3-C	-4.000	120.000	S	PR
94	Indonesia	Parapat PSI	3-C	2.700	98.920	S,M	ED
95	Indonesia	Jayapura JAY	3-C	-2.520	140.700	S	PL
96	Indonesia	Kupang KUG	3-C	-10.000	123.000	S	EA
97	Indonesia	Jakarta PACI	3-C	-6.593	106.910	S	ED
98	Indonesia	Sarong SWI	3-C	0.860	131.260	S	EA
Antarctica							
99	Antarctica	Palmer Station PMSA	3-C	-64.770	-64.050	C	ED
100	Antarctica	Georg Neumayer Base VNA	3-C	-70.610	-8.366	C	ED
101	Antarctica	South Pole SPA	3-C	-90.000	115.000	C	ED
Oceania and Pacific Ocean							
102	Papua New Guinea	Port Moresby PMG	3-C	-9.410	147.150	S	ED

No.	Location	Station name and code	Station type	Lat	Long	Rationale	Status
103	Papua New Guinea	Bialla BIAL	3-C	-5.310	151.050	S	EA
104	Australia	Narrogin NWAO	3-C	-32.927	117.233	M,C	ED
105	Australia	Fitzroy Crossing FITZ	3-C	-18.103	125.643	M,C,B	ED
106	Australia	Charters Towers CTA	3-C	-20.088	146.254	M,C	ED
107	Solomon Islands	Honiara HNR	3-C	-9.430	159.950	S	ED
108	France	Port Laguerre NOUC	3-C	-22.101	166.303	S	ED
109	Fiji Islands	Monasavu MSVF	3-C	-17.730	178.050	S	ED
110	New Zealand	Urewera URZ	3-C	-38.260	177.110	S	ED
111	New Zealand	Erewhon EWZ	3-C	-43.512	170.853	S	ED

Table 2:

Recommended IMS Auxiliary Stations on Small Islands

No.	Location	Station name and code	Station type	Lat	Long	Rationale	Status	Seismic Interest
South America								
1	Ecuador	Santa Cruz ?	3-C	-0.660	-90.230	S	PL	
2	Chile	Rapa Nui, Easter Island RPN	3-C	-27.130	-109.330	S	ED	
Atlantic Ocean								
3	United Kingdom	Ascencion Island ASCN	3-C	-7.950	-14.380	S,C	ED	
4	Spain	Taburiente TBT	3-C	28.680	-17.910	C	ED	
5	United Kingdom	Tristan da Cunha ?	3-C	-37.000	-12.500	S,C	PR	
6	South Atlantic	Location to be determined						x
Indian Ocean								
7	United Kingdom*	BIOT/Chagos Archipelago ?	3-C	-7.300	72.400	S,C	PR	
8	France	New Amsterdam Island AIS	3-C	-37.797	77.569	C	ED	
9	France	Port Alfred CRZF	3-C	-46.430	51.861	C	ED	
Oceania and Pacific Ocean								
10	Japan	Chichijima, Ogasawara JCJ	3-C	27.100	142.183	S	ED	x
11	USA	Guam GUMO	3-C	13.590	144.870	S	ED	x

* Appears without prejudice to the question of sovereignty.

No.	Location	Station name and code	Station type	Lat	Long	Rationale	Status	Seismic Interest
12	Micronesia	Ponpei PATS	3-C	7.000	158.000	C	ED	
13	New Zealand	Raoul Island RAO	3-C	-29.150	-177.520	S	PR	x
14	Western Samoa	Afiamalu AFI	3-C	-13.910	-171.780	S	ED	x
15	Cook Islands	Rarotonga RAR	3-C	-21.210	-159.770	C	ED	
16	USA	Kipapa KIP	3-C	21.423	-158.015	C	ED	
17	Vanuatu	Butte a Klehm BKM	3-C	-17.668	168.243	S	EA	x

ANNEX I

REPORT FROM THE AD HOC GROUP OF SCIENTIFIC EXPERTS THIRD TECHNICAL TEST (GSETT-3) RELEVANT TO CONSIDERATIONS OF THE SEISMIC COMPONENT OF THE INTERNATIONAL MONITORING SYSTEM

Executive Summary

The third technical test of the Ad Hoc Group of Scientific Experts (GSETT-3) is being conducted as an extensive operational test of a proposed concept for the seismic component of the International Monitoring System (IMS) designed for use under a treaty banning underground nuclear explosions. The first ten months of operation of GSETT-3 can be used to provide information on issues that are not yet resolved, but are viewed as important at this stage of the Test Ban negotiations.

The observed detection capabilities of the GSETT-3 primary network of 38 stations, supported by theoretical simulations, is a high of magnitude 4.6 in the south Atlantic Ocean region, and a low of magnitude 3.6 in parts of Australia, North America and Europe. The GSETT-3 auxiliary network of 75 stations is most dense in these same three regions, providing an opportunity to assess the value of auxiliary stations in improving seismic event location capability. For these regions, the location error ellipse area for events with body wave magnitudes above 4.0 can in fact be reduced on average by a factor of up to 4, when data from auxiliary stations are used.

Using theoretical simulations calibrated to GSETT-3, the expected detection threshold for the 50-station primary network proposed for the seismic component of IMS in CD/NTB/WP.269 is estimated to be below magnitude 4 inside all continental areas, except Antarctica.

The estimated location uncertainty of a fully calibrated primary network (i.e. taking into account local and regional seismic propagation conditions) for an event of magnitude 4.0 should be represented by an error ellipse smaller than 1,000 square kilometres inside most of the continental areas of Eurasia, North America and northern Africa; but by an ellipse greater than 1,000 square kilometres in most of the Southern Hemisphere.

Simulation of location capability improvements achieved for magnitude 4 events with proposed auxiliary networks with 30, 75, 100, 130 and 150 stations shows that - under realistic hypotheses on wave propagation and on processing optimisation, deduced from the GSETT-3 experiment - error ellipse areas in the interiors of all continents except Antarctica should be reduced to less than 1,000 square kilometres with the 100-station auxiliary network

together with the primary network. The proposed 130-station auxiliary network should allow to achieve this also in most continental margins and coastal regions, many of which are seismically very active areas.

The proposed auxiliary networks with 75 or more stations provide various degrees of enhanced coverage in the major seismic and mining zones of the world, and various backup possibilities for several primary stations. If such constraints are not taken into account, non-redundant auxiliary networks with significantly less stations might achieve location capabilities equivalent to those of the proposed 130-station network. However, source characterisation would then be more difficult to perform.

Some of the auxiliary stations are located at island sites and thus should be discussed in the context of synergy with the envisaged hydroacoustic network.

The location capabilities quoted above have been obtained by assuming a fully calibrated network of stations with complete data availability and optimised information processing. It is recognised that significant resources and time will be required to upgrade GSETT-3 to achieve the results obtained under these idealistic assumptions.

According to one Delegation, the following results were obtained: Using theoretical simulation with the method of calibrating at the currently highest achievable detectability potential, moderated by a magnitude of 0.4 the expected detection threshold for the 50-station primary network proposed for the seismic component of IMS in CD/NTB/WP.269 is estimated to be below magnitude 3.5 inside all continental areas, except Antarctica, and the detection threshold for the Eurasian area to be magnitude 3.1. The location uncertainty in this area is estimated to be less than 1,000 squared kilometres. Also, according to this Delegation, the number of auxiliary stations necessary to achieve the required goal in terms of location capability on a world-wide basis could be as low as 30.

The Working Group considered five auxiliary network proposals with 30, 75, 100, 130 and 150 stations. With the condition that calibration must be performed, the Working Group on Evaluation recommends that an auxiliary network of 100 to 130 seismic stations be included in the IMS.

It is however recognised that, well after full-scale operation of IMS has begun, when all processing stages have been fully optimised, these numbers could be further reduced without impairing global location capability.

One of the major functions of the IMS will also be to provide the participating countries with the necessary information to identify seismic sources. A partial list of source characterisation parameters has been submitted to the GSETT-3 participants, some of which are already available in the bulletin (i.e., location and depth). Steps are being taken to incorporate production of the relevant parameters in the GSETT-3 system.

As for cost issues, the results of a recent questionnaire sent to GSETT-3 participants lead to average annual operating costs for primary and auxiliary stations which did not seem to be representative enough to drive any definite conclusion, since the numbers obtained showed wide variability.

1. Introduction

This report has been prepared in order to assist the CD and its Ad Hoc Committee on Nuclear Test Ban with issues concerning the seismic component of the International Monitoring System (IMS) that are not yet resolved and are viewed as important at this stage in the negotiations. The results from GSETT-3 that are described in this report are based on the first ten months of operation of that experimental system; a comprehensive report based on a full year of operation will be prepared at the Group's February 1996 session.

2. Concept of the GSETT-3 System

In its third technical test, known as GSETT-3, the Group has conducted an extensive operational test of a proposed concept for the seismic component of the IMS designed for use under a treaty banning underground nuclear explosions. The concept tested in this experiment differs from the two previous ones chiefly in the use of a single International Data Centre (IDC) instead of several, and in the use of continuous, real-time seismic data instead of parametric data or partial waveform data pre-processed at NDCs. This experimental system also differs from other national and international institutions providing similar services chiefly in the scale of its global coverage and the rapid time frame within which the data are acquired, analyzed, and distributed. One of its goals is in fact to distribute within two days an accurate, global bulletin of seismic events, together with a set of parameters useful to identify the type of the events.

Based on its prior experience, the Group considered that a successful international seismic monitoring system must have the ability to: 1) rapidly acquire data from a global network of stations and process it at a central facility; and 2) promptly provide reliable data, in a convenient manner, to all participating States for their national verification purposes.

The Group considered several features to be essential to meet these goals: 1) the collection, processing, and distribution of data must be as fully automated as possible; 2) a permanent archive of all data collected or generated by the system must be maintained; 3) the system architecture must permit modifications and improvements, and provide for data security and quality control; and finally, 4) the system must be cost effective. The system envisaged to meet the goals and to provide the essential features, as described above, consists of three main operational elements: 1) a single IDC; 2) multiple NDCs; and 3) a two-tiered global network of primary and auxiliary stations. These elements are described below.

The IDC is the central component of the seismic monitoring system. It receives continuous data and data segments from primary and auxiliary stations, respectively. It processes these data to form a daily bulletin or list of world-wide seismic events. This bulletin includes, among other things, the time, location, and other characterisation parameters for each reported event. Automation is used to the greatest extent possible in IDC processing. The IDC serves as the central distribution point to NDCs of all raw data it receives and of all of its data processing products. The IDC monitors the technical performance of all primary and auxiliary stations for quality control purposes. It also receives other seismological data, such as national and regional bulletins, from NDCs.

The NDCs are the responsibility of individual States and are seen as the primary users of IMS data and products in support of national verification needs. NDCs (or co-operating regional facilities in some cases) operate primary and auxiliary stations and are responsible for the transmission of data from these stations to the IDC. NDCs may receive from the IDC any or all data and IDC products.

While primary stations are the backbone of the seismic component of the IMS, both primary and auxiliary stations are required to meet high technical standards regarding sensitivity, instrument response, and signal digitisation characteristics. Primary stations are the backbone because they transmit all data continuously to the IDC either directly or through an NDC. These continuous, real-time data are used to detect events and to make preliminary location estimates. Data segments from auxiliary stations are retrieved by the IDC from the station or a participating NDC. The auxiliary stations called upon are usually the closest and will most improve the location accuracy of the events. These data segments are used to supplement the continuous data from the primary stations in order to locate seismic events with greater accuracy, and to provide event characterisation parameters from additional stations.

3. Detection and Location Capabilities

The GSETT-3 primary network has grown from 27 stations in January to 38 stations in October. However, it is less optimally distributed than the envisaged IMS primary seismic network of 50 stations, because GSETT-3 has had to rely on voluntary contributions from participating countries. Nevertheless, observations of the capabilities of the GSETT-3 network provide insight into the capabilities of the envisaged IMS primary network. The GSETT-3 auxiliary network has grown from 25 stations in January to 75 stations in October. In some portions of the globe the density of GSETT-3 auxiliary stations is in fact greater than that envisaged for the IMS network. This provides an opportunity to assess the contributions the auxiliary stations can make to improving seismic event location capability.

3.1 GSETT-3 Detection Capability

The detection capability of the GSETT-3 primary network is defined as the lowest seismic magnitude at which there is a 90 % probability that there will be sufficient information recorded for the event to be located by the primary network and appear in the GSETT-3 Reviewed Event Bulletin (REB).

This capability will vary with geographical region, and can be established by assessing the completeness of the REBs in a variety of ways: (1) comparison of the numbers of earthquakes in the REB as a function of magnitude with numbers expected in different regions based on empirical magnitude/frequency relations; (2) comparison with independent seismic event bulletins that may be available on a local, regional or global basis; or (3) theoretical simulations based on a knowledge of the decay of seismic waves with distance and of the detectability of the waves at stations with known seismic noise properties. The simulations assume that the availability of data at all stations of the primary network is very high, that these stations are sending their data to the IDC in a timely fashion, and that all automatic processing stages have been optimised. Each of these methods has been used to determine the GSETT-3 detection capability.

The observed detection capabilities of GSETT-3 over the period July to September 1995, based on a combination of methods 1) and 2), are as follows. Averaged over world-wide seismicity, the mean global detection threshold is at a body wave magnitude of 4.2. The highest threshold is magnitude 4.6 in the south Atlantic ocean region. Most of the Northern Hemisphere and Australia are below magnitude 4.2. However, within both North America and Europe, there is a considerable variation from less than 3.6 to about 4.4, depending on the region considered.

Observations can of course only be made where a statistically relevant number of events has been recorded by the REB and by an independent reference bulletin. Theoretical simulations of GSETT-3 detection capabilities allow detection thresholds to be estimated also for regions with few or no observed events. They show good agreement with results observed in seismic regions, providing confidence that the simulations will be valid when applied to the primary-station seismic network in the IMS.

3.2 GSETT-3 Location Capability

The accuracy with which a seismograph network can locate a seismic event depends on two principal factors: the number and distribution of the stations detecting the event; and the prior knowledge of the seismic wave propagation speeds. The uncertainty is described as the area of an ellipse on the earth's surface within which there is a 90% probability of having the true location of an event.

The knowledge of seismic wave propagation speeds applies within the whole earth, but more importantly at local and regional distances where they may vary considerably depending on geological conditions. Establishing these important local and regional differences and applying them routinely in the IDC processing is what the Group means by " calibration " of the network. Without calibration, in many regions the locations might be systematically biased, giving a location error larger than theoretically estimated. In other words, for an uncalibrated network one obtains the formal precision (uncertainty ellipse) rather than the actual location accuracy. Calibration of the GSETT-3 network is under way, but so far few results are available.

The primary/auxiliary network concept has been devised as a cost effective means of involving a greater number of stations in seismic event location without incurring the cost of transmitting all of the data from these stations continuously to the IDC. The growth in the number of auxiliary stations from 25 to 75 during the first ten months of GSETT-3 has produced a significant improvement in location uncertainty.

Locations of REB events have been recomputed using primary stations only, suppressing the auxiliary network contribution. Comparison of the locations computed with both sets of stations shows - for events with a bodywave magnitude above 4.0 - a reduction of the error ellipse area by a factor of up to 4, for those regions where the primary and auxiliary networks are more or less complete.

3.3 Predicted Capabilities of the Seismic Component of the IMS

By adjusting the simulation methods in such a way as to render the observed performance during GSETT-3, and in a second step applying them to a set of suggested networks for the seismic component of IMS, an extrapolation of GSETT-3 capabilities to the future IMS is obtained. However, the current GSETT-3 network is largely uncalibrated and its auxiliary stations have yet to be exploited to their full capacity. Therefore, such an extrapolation constitutes a non-optimised estimate. This non-optimised scenario would apply by simply bringing the number and distribution of GSETT-3 stations up to IMS levels and leaving all seismic data processing at the state of September 1995.

By contrast, purely theoretical simulations of network capabilities usually make a number of idealising assumptions and lead to an estimate appropriate for an optimised system. This scenario would describe an ideal network with close to 100% data availability and utilisation, optimised data processing and full calibration. This is what would be expected well after full-scale operation of IMS has begun, the required time being dependent on the resources that can be made available for calibration.

3.3.1 Predicted detection capability

Looking at predicted detection capabilities, optimised and non-optimised scenarios do not differ much, as primary station data availability during GSETT-3 has been high - at the time when the REB is processed - and as calibration is of minor importance for detection. The expected detection thresholds for the 50 station primary network tentatively defined by the NTB Ad Hoc Committee (CD/NTB/WP.269) would then be as follows. The threshold should be below magnitude 4.0 inside all continental areas except Antarctica. It should be lower, at magnitude 3.6 or less, in the interiors of Eurasia, North America and Australia; and higher, at magnitude 4.4, in parts of the southern Atlantic Ocean.

According to one Delegation: Other theoretical simulations with the method of calibrating at the currently highest achievable detectability potential moderated by a magnitude of 0.4, obtained similar results but with a general reduction of detection threshold magnitude of 0.5 for all areas, namely magnitude 3.5 thresholds for the majority of the areas, and magnitude 3.1 for the Eurasian area.

3.3.2 Predicted location capability

As far as location capabilities are concerned, optimised and non-optimised estimates differ more widely. However, in the following, we concentrate on optimised scenarios. We shall describe only the general features of the results. Detailed information can be found in GSE/WGE/15. Estimated location capability for the 50-station primary network supplemented with

a network of 30, 75, 100, 130 and 150 auxiliary stations, in terms of location uncertainty ellipse area in square kilometres for an event of magnitude 4.0 are shown in Fig.2-6 in GSE/42/WGE/15.

The expected location uncertainty of the fully calibrated 50 primary station network without auxiliary stations is, for an event of magnitude 4.0, an error ellipse area larger than 1,000 square kilometres in Central America, Indonesia, and in nearly all of the Southern Hemisphere, including southern Africa, Antarctica, and most of South America and Australia. The error ellipse has an area of less that 1,000 square kilometres inside most of the continental areas of Eurasia, North America and Northern Africa. Thus, according to these simulations and to the experience gained during GSETT-3, the primary network cannot, by itself - even according to the optimised scenario - give an adequate location capability in all regions without auxiliary stations.

Five auxiliary networks have been considered, with 30, 75, 100, 130 and 150 stations, most of which are existing or planned by seismological agencies. The 30 stations auxiliary network was proposed by one Delegation. The auxiliary networks with 75 or more stations have been provided by the Working Group on Planning. (see Fig.2 in GSE/42/WGE/15)

Assuming that calibration has been performed, the 30 station auxiliary network together with the primary network should reach a location uncertainty of 1,000 square kilometres or less in the interiors of most of Eurasia, Northern America, Northern Africa, and Australia, for all events with a bodywave magnitude above 4.0. But this would not be achieved in most oceans; near Indonesia and in significant parts of the southern Hemisphere, including portions of Central and South America, southern Africa, most of Australia and nearly the whole of Antarctica. (see Fig.3 in GSE/42/WGE/15)

Under the same scenario, the 75 station auxiliary network together with the primary network would decrease location uncertainty to the desired level in nearly all of Central America and south Africa, and near Indonesia. This capability would not be achieved in most oceans and continental margins, and in Antarctica. Also, considerable redundancy and limited possibilities for backup of primary stations are made available in this 75 auxiliary station network. (see Fig.4 in GSE/WGE/15)

As for the 100 station auxiliary network, there is not much change in the shape of the zones where a location uncertainty of 1,000 square kilometres or less can be achieved for magnitude 4.0 events, except for the most southern parts of Africa and in Central America. The desired location uncertainty is still not reached in most oceans and in significant parts of Antarctica, or in some continental margins and coastal regions. (see Fig.5 in GSE/42/WGE/15)

Considering the 130 station auxiliary network, the desired location capability should also be achieved in continental margins and coastal regions, in the northern Indian ocean, and in the south-western Pacific. This is possible because stations located on islands have been added. Moreover, the 130 station auxiliary network provides enhanced coverage of the major seismic zones of the world, and enhanced backup for several primary stations. However, the location uncertainty remains larger than 1,000 square kilometres for magnitude 4 events in significant parts of the oceans, in western Antarctica, and in the most southern part of South America. (see Fig.6 in GSE/42/WGE/15)

Finally, the 150 station auxiliary network leads to only marginal improvement in location uncertainty for events above magnitude 4.0.

Thus, auxiliary networks of 100 to 130 stations should provide the desired location capability in most regions of the world, backup for several primary stations, and extensive source characterisation data.

It must however be stressed again that, to achieve the location uncertainties quoted above, full calibration of the network is necessary. This is a well understood process, but it requires a large body of data being collected for each region, before it can be started. Such data will only very slowly accumulate in seismically less active regions. Moreover the cost involved in terms of human resources should not be underestimated.

3.3.3 Effect of azimuth coverage on location uncertainty

An important aspect of accurate event location is a wide azimuthal distribution of the stations with respect to the event. Wide and even azimuthal coverage is in fact required to reach error ellipse areas close to 1,000 square kilometres.

Consider a circle around each hypothetical epicentre divided into eight parts (octants). For adequate location capability, at least five out of eight octants should have contributing seismic stations within 3,000 km. The proposed network of 130 auxiliary stations, together with the primary network, can in fact reach a global average octant coverage of five or more, while with proposed auxiliary networks with less stations this can not be realised. On the other hand, going to the proposed 150 auxiliary station network increases the coverage only marginally.

4. Source Characterisation Parameters

Discussions regarding the functions of the future IMS will take place during the next CD Session, and it is expected that there will be considerable clarification. One of these functions

may require that the seismic component of the IMS provides source characterisation parameters to assist State Parties in their verification program. A non-exhaustive list of such parameters has been submitted to the GSETT-3 participants in order to access its relevance and to request additional parameters that NDCs may want to use for event identification purposes.

Current discrimination techniques are based on event parameters such as location, depth, magnitude, and also on various measurements made on the waveforms. All efficient discrimination methods apply various combinations of such parameters in order to assess the origin of an event.

The event location can be useful in the sense that if the source can be accurately located under a heavily populated area, it would be unlikely to view it as a planned explosion; if it is located at a depth greater than can possibly be drilled, then the source is unlikely to be an explosion; while if it is located under a non seismic region, it could more likely be an explosion. The usage of these two parameters (location and depth) assumes a strong confidence in their determination, which has however not been achieved during GSETT-3, especially concerning depth estimation for shallow events.

Magnitude estimates are also useful for source characterisation because one of the most important discriminants for large events is the ratio of body wave to surface wave magnitude. Therefore the IDC is currently developing methods to ensure that magnitude estimates are reliable. Other parameters take advantage of the differences in the energy radiation patterns between earthquakes and explosions. These differences can be seen in the frequency contents and the envelopes of the signals, and on amplitude ratios between different types of seismic phases. One should however keep in mind that these parameters are highly region-dependent and that a careful calibration would be required before any meaningful conclusion can be drawn.

As a preliminary investigation into the methodology involved in the production of various source characterisation parameters, measurements have been made on data from a set of events that occurred between 11 January and 11 February, 1995, and the resulting parameters have been stored in the IDC database for further evaluation by GSETT-3 participants.

Moreover, the GSETT-3 system is being developed in such a way as to allow flexibility and incorporation of additional source characterisation parameters which may be developed at NDCs or other institutions.

Finally, no assumptions have been made so far, regarding any decisions on which parameters may be required for the future ISMS, and on allocation of responsibility for any political judgements to be made.

5. Costs of Primary and Auxiliary Seismograph Stations

The capital costs of seismograph stations and the costs of the experimental IDC have been described in previous reports (e.g., CD/1254, CD/NTB/WP.224 and CD/NTB/WP.269). In order to gather information on the operating costs of primary and auxiliary stations the Group has received information from 16 of the 35 NDCs taking part in GSETT-3 via a questionnaire distributed by the Working Group on Evaluation. The information available so far is thus restricted to this limited sample, which shows wide variation and may not necessarily be representative.

This sample questionnaire demonstrated that the average annual cost of operating a primary station could vary largely depending on various conditions on site accessibility, NDC organisation and reported cost estimation technique. Therefore the global operating cost of a 50 station primary network is still estimated to be of the order of 9.5 MUSD, as already stated in CD/NTB/WP.269. These costs include the communications costs from the station to the NDC, and the expenditures associated with operation and maintenance.

The operating costs of a three-components auxiliary station would be one half to two thirds that of a primary station, because of the reduced communication costs, but the personnel costs for operation and maintenance would be about the same.

The costs of primary station communications from the station or NDC to the IDC vary greatly, depending on the type of communication used. A previous estimate in report CD/1254 was 8 MUSD for a primary network, but this could be a factor of two higher or lower in the eventual IMS, depending on the location of the IDC and the communication facilities available at that time.

6. Summary and Conclusions

The first ten months of operation of GSETT-3 have provided valuable information to address some of the issues relevant to considerations of the seismic component of IMS that are not yet resolved, but are considered important at this stage of the Nuclear Test Ban negotiations. In particular, the expansion of the GSETT-3 auxiliary stations network from 25 to 75 stations has allowed a number of assessments to be made of the value of these stations in improving seismic event location capability.

In using GSETT-3 results to forecast the capabilities of the seismic component of the IMS, it is concluded that the IMS primary seismic network alone, even if fully calibrated, cannot achieve the desired location uncertainty area of less than 1,000 square kilometres for events with magnitudes 4.0, except near the centres of continents.

Under the optimised (i.e., calibrated) scenario, adequate location capability inside and on the margins of continents, many of which are seismically active, and in most ocean areas, should be achieved by an auxiliary network of 100 to 130 stations together with the primary network. Moreover, such networks would provide enhanced coverage of most seismically active regions and of major mining regions in the world, and also provide satisfying back-up for primary stations. In addition, they should be dense enough so as to permit the computation of reliable source characterisation parameters for most events with magnitudes 4.0 or above. Incorporating additional auxiliary seismic stations would improve this situation only marginally.

On the other hand, if synergy with hydroacoustic techniques can be fully exploited, an auxiliary network with about 100 stations could be enough to fulfil similar requirements and reach equivalent location capabilities.

However, in the view of one Delegation: According to theoretical simulations with the method of calibrating at the currently highest achievable detectability potential moderated by a magnitude of 0.4, the detection threshold magnitude for the central area of Eurasia was reduced to 3.1, with a location uncertainty area of less than 1,000 squared kilometres, with the following conclusions: 1) the monitoring capability at the lowest threshold areas is contributed mainly by arrays and three-component stations contributing only in special cases; 2) Since auxiliary stations to be added will only be three-component stations, such stations will not improve the lower magnitude threshold and its locating accuracy; 3) With the setting up of 30 auxiliary stations, the location uncertainty area will be less than 1,000 square kilometres for events with magnitude greater or equal to 3.9 globally.

The Working Group considered five auxiliary network proposals with 30, 75, 100, 130 and 150 stations. With the condition that calibration must be performed, the Working Group on Evaluation recommends that an auxiliary network of 100 to 130 seismic stations be included in the IMS.

Finally, preliminary investigations have begun into source characterisation parameters that may be provided by the IDC to assist participating States with their verification requirements. When requirements for source characterisation parameters have been specified, steps will be taken to incorporate production of the adequate parameters into the GSETT-3 system.

Annex 2

Draft work programme for the next (43rd) session

1. Review and finalize an evaluation report on the first year of GSETT-3
2. Review and finalize plan for the GSETT-3 network to IMS network transition
3. Review of GSETT-3
4. Presentation and review of national investigations into relevant matters
5. Discussion of future plans
6. Answer possible questions relating to GSETT-3 from the NTB Ad Hoc Committee or its Working Group on Verification
7. Submission of a progress report to the Conference on Disarmament
8. Other matters